CHAPTER 5

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EFFECT OF FARMYARD MANURE AND INORGANIC FERTILIZER ON SORGHUM GROWTH AND YIELD AND SOIL PROPERTIES IN A SEMI-ARID AREA IN ETHIOPIA. I. SORGHUM GROWTH, YIELD AND N USE

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ABSTRACT

A field experiment was conducted to assess the effect of the combined use of farmyard manure (FYM) and inorganic fertilizer on the growth and yield of sorghum and on soil chemical properties in a semi-arid area in NE Ethiopia. Twelve treatments comprising factorial combinations of four levels of FYM (0, 5, 10 and 15 t ha^{-1} $annum^{-1}$) and three levels of inorganic fertilizers (0, 50 and 100% of the recommended rate) were compared in a randomised complete block design with three replications over a period of six years. The results revealed significant improvements in the growth and yield of sorghum due to the main and interaction effects of FYM and inorganic fertilizer application. Application of FYM, inorganic fertilizers and their different combinations increased aboveground biomass and grain yield significantly. Grain yields were greater from combinations of FYM and inorganic fertilizer than either applied alone. Combined application of FYM and inorganic fertilizer also increased post-anthesis dry matter production. FYM application produced the highest N uptake, N concentration, N use efficiency and grain protein concentration and grain protein yield. Application of FYM in combination with 50% of the recommended inorganic fertilizer rate resulted in a grain yield equivalent to, or greater than, that for 100% of the recommended inorganic fertilizer rate, thus effecting a 50% saving of inorganic N and P fertilizer. Application of 5, 10 and 15 t FYM ha^{-1} in combination with 100% of the recommended fertilizer rate and 5, 10 and 15 t FYM ha^{-1} in combination with 50% of the recommended fertilizer rate can be recommended for farmers who can and can not afford to buy inorganic fertilizers, respectively.

INTRODUCTION

Sorghum (*Sorghum bicolor* L. Moench) is an important crop in the semi-arid areas of NE Ethiopia (1). However, its productivity is very low (approximately 1.2 t grain ha^{-1}) and variable due partly to poor fertility status of soils (2). As in many semi-arid environments where the management of organic residues is poor and the rate of organic matter decomposition is fast, the organic matter content and the fertility status of the soils in NE Ethiopia is low. These soils can no longer sustain production with the existing fertility status. The maintenance of the fertility status of the soils is essential for optimum and sustained productivity. Inorganic fertilizers can be used to replenish soil nutrients and increase crop yields but are too costly for the resource poor farmers of NE Ethiopia. Furthermore, concerns on soil exhaustion and nutritional imbalances, arising from increased and indiscriminate use of inorganic fertilizers, necessitates research on organic manure (Gaur *et al*., 1984 as cited by 3). The use of organic manure alone may not, however, be enough to maintain the present level of crop production because of limited availability and relatively low nutrient content (4).

An integrated nutrient management program in which both organic manure and inorganic fertilizer are used has been suggested as a rational strategy (4). It is commonly believed that the combination of organic and inorganic fertilizer will increase synchrony and reduce nutrient losses (5). This is important not only in enhancing the efficiency of the fertilizers but also in reducing environmental problems that may arise from their use. The application of organic substances, including farmyard manure, apart from supplying nutrients, also provides growth regulating substances (Flaig, 1974 as cited by 6) and improves the physical (7), chemical (8) and microbial (9) properties of the soil. Unlike mineral fertilizers, nutrients contained in organic manures are released more slowly and are stored for a longer time in the soil, thereby ensuring a longer residual effect (3). The results of many studies conducted in different parts of the world on integrated nutrient management are variable, presumably due to the climatic, soil type and quality effects on the performance of the organic component of the system (10).

Farmyard manure is readily available in the crop-livestock farming systems of NE Ethiopia and it has potential for use in the fertilization schedule of sorghum in order to reduce dependence on inorganic fertilizers, while maintaining good soil health. However, information on the effect of the combined use of farmyard manure and inorganic fertilizers on the growth, development and yields of sorghum under the semi-arid environments of NE Ethiopia is not available. Research was conducted to study the effects of the integrated use of farmyard manure and inorganic N and P on the growth and yield and N use of rainfed sorghum and on soil chemical properties under semi-arid environments.

MATERIALS AND METHODS

Study Site

This experiment was conducted on the same plots for six years (1997-2002) on a Eutric fluvisol at Kobo research site of Sirinka Agricultural Research Centre in Ethiopia. The site is situated at 12^0 9'N, 39^0 38'E at an altitude of 1470 m above sea level, has a semi-arid climate with mean annual maximum and minimum air temperatures of 29^0 C and 15^0 C (1976-2002) and mean annual rainfall of 649 mm (1973-2002). The rainfall is characterized by an uneven and unpredictable distribution. The 0-23 cm horizon contains on average 34% clay, 52% silt and 14% sand, with a pH of 7.5 (1:2.5 in water), 1.20% organic C, 0.08% total N, 12.5 mg kg^{-1} available (Olsen) P, 2.3 meq 100 g^{-1} K, 34.23 meq 100 g^{-1} Ca, 11.41 meq 100 g^{-1} Mg, 1.58 meq 100 g^{-1} Na, and CEC of 50.6 meq 100 g^{-1}.

Experimental Design and Procedure

Treatments were annual application of factorial combinations of four rates of farmyard manure (0, 5, 10 and 15 t ha^{-1} $annum^{-1}$ on dry weight basis) and three rates of inorganic fertilizer (0, 50 and 100% of the recommended rate). The locally recommended rate for a sorghum yield potential of 3 t ha^{-1} is 41 kg N ha^{-1} and 20 kg P ha^{-1}. For simplicity, the three inorganic fertilizer rates will hereafter be referred to as 0%, 50% and 100% fertilizer. The experimental design was a randomized complete block with three replications.

FYM was collected from neighbouring farmers' pens, mixed thoroughly, weighed for each plot, spread evenly, and incorporated into the soil a month before planting. The N, P and K contents of the FYM, determined before application are supplied in Table 1, varied year to year because of source and seasonal effects.

Table 1. N, P and K composition of FYM and resulting annual addition of N, P and K to the soil.

	N, P, K content of FYM (%)			Addition of N, P and K to the soil (kg ha^{-1})								
				5 t			10 t			15 t		
Year	N	P	K	N	P	K	N	P	K	N	P	K
1997	0.21	0.78	Nd	10.3	39.0	Nd	20.6	78.0	Nd	30.9	117.0	Nd
1998	0.21	0.44	Nd	10.4	22.2	Nd	20.8	44.4	Nd	31.2	66.6	Nd
1999	0.19	0.52	Nd	9.7	25.9	Nd	19.3	51.8	Nd	29.0	77.7	Nd
2000	0.19	0.14	Nd	9.5	6.9	Nd	18.9	13.7	Nd	28.4	20.6	Nd
2001	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
2002	1.38	0.41	2.87	69	20.5	143.5	138	41.0	287.0	207	61.5	430.5

Nd = Not determined

Urea and diammonium phosphate (DAP) were used as inorganic fertilizer sources. Half of the urea and all the DAP were applied in the row prior to planting and incorporated into the soil. The remainder of the urea was side dressed at the six to eight leaf stages. Sorghum cultivar 76 T1 #23 was hand drilled in 75 cm rows and thinned to an interplant spacing of 15 cm to obtain a plant population of 88 888 plants ha^{-1}. Gross plot size was 5.25 m wide by 6 m long. Hand weeding and insect control were conducted on an as-needed basis. After discarding border rows two rows were hand harvested for the determination of grain yield at maturity. Grain yields were adjusted to 12.5% moisture content. Harvest index was calculated as the ratio of grain yield to aboveground biomass. Three plants visually judged as representative of the plot were harvested at anthesis (69 days after emergence) and maturity (111 days after emergence) stages of development for the determination of dry mass production. The net amount of biomass produced after anthesis was calculated as the difference between the biomass at anthesis and maturity (11). The amount of pre-anthesis biomass mobilized to grain was calculated as the difference between grain yield at maturity and the net biomass produced during grain filling (11).

Sorghum plant samples for determination of N uptake were collected at harvest. Plant samples were oven dried at 70^0 C to constant weight. Grain and stover samples were ground separately to pass through a 1 mm sieve. The N content of plant samples was determined by the micro-Kjeldahl method (12). The N uptake in the grain and stover was estimated by multiplying the concentrations with grain and stover yields. Whole plant N uptake was calculated by adding the uptake in the grain and stover. Grain protein content was calculated as %N in the grain x 6.25 (13) and grain protein yield as grain protein content x grain yield/100 (14). Nitrogen harvest index (NHI) was calculated as the ratio of grain N uptake to whole plant N uptake. Nitrogen use efficiency was calculated as (yield in fertilized plots – yield in control plots)/applied inorganic fertilizer N kg ha^{-1} (15).

Data from the 1997 season were not included, as a severe drought had resulted in crop failure. Post-anthesis dry matter production, pre-anthesis biomass mobilization and all N related traits, as well as grain protein concentration and grain protein yield, are based on data from the 2002 season after the treatments had been applied for six years.

Analyses of variance were performed using the SAS statistical program (SAS V8.2, SAS Institute Inc., Cary, NC, USA) for individual years and the pooled data. Analyses of variance for stover yield, panicle yield, grain yield, total aboveground biomass, thousand seed weight and harvest index were done after pooling data over years. Pooled data analyses were performed after testing the homogeneity of error variances using Bartlett's test (16). Whenever treatment differences were found to be significant, based on results of *F*-test, critical differences were calculated at 5% level of probability using Duncan's Multiple Range Test.

Regression model for yield stability (Y = a + be, where e is the environmental index) analysis followed the method previously used by Raun et al. (17) and Yamoah et al. (15). Stability analysis of yields of each individual treatment was computed using the mean of all treatments in each year as an environmental yield index. Performance of individual treatments was then regressed (fit to a linear model) against the environmental index. Systems for which the slope of the linear regression was smaller were considered as more stable or less responsive (18).

RESULTS AND DISCUSSION

Dry Matter Accumulation

Post-anthesis dry matter production and biomass mobilization

Post-anthesis dry matter production was affected by the interaction effects of FYM and inorganic fertilizer treatments (Table 2). The combined application of FYM and inorganic fertilizers considerably increased post-anthesis dry matter accumulation compared to the control. The highest post-anthesis dry matter accumulations of 475 and 458 g m^{-2} were recorded in the plots receiving 10 t FYM ha^{-1} along with 50% fertilizer and 15 t FYM ha^{-1} along with 100% fertilizer, respectively. The lowest post-anthesis dry matter accumulation of 97 g m^{-2} was recorded in the control plot. This could be explained by the postulated slow release and continuous supply of N from the FYM component, which might have increased leaf area duration and thus promoted higher rates of photosynthesis during grain filling.

Increased periods of leaf greenness and thus increased post-anthesis dry matter accumulation under the combined use of FYM and inorganic fertilizers could also be ascribed to increased soil water availability. It was observed that FYM applications increased the soil N and water holding capacity. Post-anthesis dry matter accumulation in plants that received no FYM was found to be significantly less.

Similar to post-anthesis dry matter accumulation, pre-anthesis biomass mobilization to the grain varied between the FYM x inorganic fertilizer interaction effects (Table 2). The amount of pre-anthesis biomass mobilized to the grain was significantly lower with the combined use of FYM and inorganic fertilizer than either alone. The least pre-anthesis biomass mobilization of 26 g m^{-2} was recorded for the highest fertility level (15 t FYM ha^{-1} plus 100% inorganic fertilizer) as compared to the highest biomass mobilization of 417 g m^{-2} in the control plot. Plants that did not receive FYM mobilized substantial amounts of pre-anthesis biomass to the grain.

The lower pre-anthesis biomass translocation with the combined application of FYM and inorganic fertilizers could be due to the continuation of photosynthesis and assimilate supply to the grain during the grain filling period as a result of increased N supply and soil water availability, thus reducing the need for translocation of pre-anthesis assimilates. This effect was confirmed by the higher post-anthesis biomass accumulation in the plots, which received the combined application of FYM and inorganic fertilizer. Muchow (11) indicated that large amounts of biomass translocation to the grain are especially evident under low soil fertility conditions, which supports the current observation that lower biomass was translocated under high soil fertility conditions.

Table 2. Effect of the combined use of FYM and inorganic fertilizers on post-anthesis dry matter accumulation (PADMA) and pre-anthesis biomass mobilization (PABM) in 2002.

	PADMA (g m^{-2})				PABM (g m^{-2})			
FYM	0 F^{++}	50 F	100 F	Mean	0 F^{++}	50 F	100 F	Mean
0 t ha^{-1}	97d	357abc	187cd	214B	417a	111bcd	392a	307A
5 t ha^{-1}	249bcd	397ab	299abc	315AB	256abc	171bcd	233a-d	220AB
10 t ha^{-1}	433ab	475a	314abc	407A	65cd	114bcd	247a-d	142B
15 t ha^{-1}	422ab	240bcd	458a	373A	77bcd	295ab	26d	133B
Mean	300A	367A	314A		203A	173A	224A	

$^{++}$ Indicates % of the recommended inorganic fertilizer rates. Means within columns and rows followed by the same lowercase letters; means within rows followed by the same uppercase letters; and means within columns followed by the same uppercase letters are not significantly different at P≤0.05.

Stover and aboveground biomass yield at harvest

Both FYM and inorganic fertilizer treatment main effects were significant for stover yield at harvest, whereas the FYM x inorganic fertilizer interactions were not significant. Averaged across inorganic fertilizer treatments, the application of 10 and 15 t FYM ha^{-1} gave significantly greater stover yields (4 274 and 4 648 kg ha^{-1}, respectively) compared to the FYM control (3 853 kg ha^{-1}) (Table 3). Application of 50 and 100% inorganic fertilizer, averaged across FYM treatments, also gave significantly greater stover yields (4 313 and 4 605 kg ha^{-1}, respectively) compared to the inorganic fertilizer control (3 793 kg ha^{-1}) (Table 3). Responses of stover yield to FYM and inorganic fertilizers, along with grain yield increases, have implications for agriculture in NE Ethiopia, where stover is an important source of feed and fuel and is as economically important as the grain.

Aboveground biomass yield followed a similar trend as the stover yield (Table 3). Averaged across inorganic fertilizer treatments, application of FYM increased aboveground biomass yield over the FYM control. The highest aboveground biomass yield of 9 750 kg ha^{-1}was produced on plots where 15 t FYM ha^{-1}were applied. Aboveground biomass yield with the application of 50 and 100% inorganic fertilizer, averaged across FYM treatments, were greater (9 177 and 9 567 kg ha^{-1}, respectively) than the inorganic fertilizer control (8 158 kg ha^{-1}). The FYM x inorganic fertilizer interaction effects were not, however, significant.

Table 3. Effects of FYM and inorganic fertilizers on stover and aboveground biomass yield at harvest (data pooled over five growing seasons).

FYM	Stover yield (kg ha^{-1})				Aboveground biomass yield (kg ha^{-1})			
	0 F^{++}	50 F	100 F	Mean	0 F^{++}	50 F	100 F	Mean
0 t ha^{-1}	3295a	4101a	4162a	3853C	7524a	8384a	8781a	8230C
5 t ha^{-1}	3881a	4003a	4631a	4172BC	8235a	8849a	9637a	8907B
10 t ha^{-1}	3966a	4422a	4435a	4274AB	8240a	9502a	9206a	8983B
15 t ha^{-1}	4029a	4725a	5189a	4648A	8634a	9972a	10643a	9750A
Mean	3793B	4313A	4605A		8158B	9177A	9567A	

$^{++}$As in Table 2. Means within columns and rows followed by the same lowercase letters; means within rows followed by the same uppercase letters; and means within columns followed by the same uppercase letters are not significantly different at P≤0.05 for each comparison.

Grain Yield

Data presented in Tables 4, 5 and 6 indicate the main and interaction effects of FYM and inorganic fertilizer treatments on grain yield in individual years and yield pooled across years. In all years (except in 1998), grain yield significantly differed between the FYM x inorganic fertilizer interaction effects. Similar grain yield response trends to treatment effects were observed each year and only the pooled grain yield data is discussed.

The main and interaction effects of FYM and inorganic fertilizer treatments on grain yield averaged over years (pooled data) are illustrated in Table 6. Greater grain yields were obtained with the combination of FYM and inorganic fertilizer than with either manure or inorganic fertilizer alone. The combined application of 5, 10 and 15 t FYM ha^{-1} with 50 and 100% of the recommended inorganic fertilizer rate significantly increased grain yield over the control (Table 6). The highest grain yield of 4 535 kg ha^{-1} was obtained from the plots receiving the highest fertility level (15 t FYM ha^{-1} plus 100% of the recommended inorganic fertilizer rate) and the lowest yield of 3 340 kg ha^{-1} was obtained from the control.

Increases in grain yield with the combined applications of FYM and inorganic fertilizers are ascribed to the addition of NPK and other essential nutrients from the FYM component and its favourable effect on the physical, chemical and microbial properties of the soil (19, 20). Satyanarayana et al. (21) indicated that FYM plays an important role in improving soil permeability to air and water and water stable aggregates, thus improving soil properties and nutrient uptake, which results in greater growth and yield. Similar long term studies on different crops have shown increased yields due to the application of FYM and these effects were largely attributed to improved soil organic matter, and soil physical, chemical and microbial properties with the application of FYM (9, 21). Application of FYM also influences plant growth physiologically by providing growth regulating substances (Flaig, 1974 as cited by 6).

The combined use of FYM and inorganic fertilizers, in addition to the additive effect on nutrient supply and improvement of soil physical conditions, checks nitrogen losses and conserves soil N by forming organic-mineral complexes thereby ensuring continuous N availability and greater yields (21). The increased grain yields, from the combined application of FYM and inorganic fertilizers, are in agreement with the results of other studies on sorghum (22), rice (3, 23, 24), soybean (25), maize (26), and wheat (23, 24).

Application of 5 t FYM ha^{-1} in combination with 50% of the recommended inorganic fertilizer rate resulted in a grain yield comparable with that obtained from applying 100% of the recommended inorganic fertilizer rate. Further increases in the FYM rate to 10 and 15 t ha^{-1} and combining with 50% of the recommended inorganic fertilizer rate also resulted in statistically better yields than applying 100% of the recommended inorganic fertilizer rate alone. This suggests that, by applying FYM along with 50% of the recommended inorganic fertilizer rate a cost saving on inorganic fertilizers worth of 20 kg N ha^{-1} and 10 kg P ha^{-1} can be made, with the additional benefit of improving the physical and chemical conditions of the soil. Thus, application of FYM has potential of not only improving crop yield and soil fertility, but also of reducing dependence on inorganic fertilizers. Although soil organic matter and total N improvements observed in this study were cumulative for FYM treated plots, the time variable was not related to the sorghum yield, suggesting that there were no long term cumulative effects of annual application of FYM on productivity of sorghum.

Table 4. Effect of the combined use of FYM and inorganic fertilizers on sorghum grain yield (kg ha^{-1}) in 1998 and 1999.

	1998				1999			
FYM	0 F++	50 F	100 F	Mean	0 F++	50 F	100 F	Mean
0 t ha^{-1}	3079a	3201a	3610a	3297B	3422de	3257e	4568bc	3749B
5 t ha^{-1}	3332a	3526a	3843a	3567AB	3501de	4314bc	5003ab	4273A
10 t ha^{-1}	3185a	3646a	3904a	3578AB	3415de	4020cd	5331a	4255A
15 t ha^{-1}	3263a	4262a	4210a	3912A	3994cd	4659abc	4482bc	4378A
Mean	3215B	3659A	3892A	3589	3583C	4063B	4846A	4164

++ As in Table 2. Means within columns and rows followed by the same lowercase letters; means within rows followed by the same uppercase letters; and means within columns followed by the same uppercase letters are not significantly different at P≤0.05.

Table 5. Effect of the combined use of FYM and inorganic fertilizers on sorghum grain yield (kg ha^{-1}) in 2000 and 2001.

	2000				2001			
FYM	0 F++	50 F	100 F	Mean	0 F++	50 F	100 F	Mean
0 t ha^{-1}	3435cde	3217e	3319de	3324C	2982d	3323b-d	3000d	3102C
5 t ha^{-1}	3491cde	3623b-e	3504cde	3539B	3493b	3286b-d	3428bc	3402B
10 t ha^{-1}	3677bcd	3982b	3488cde	3716B	3274b-d	3097cd	3315b-d	3228BC
15 t ha^{-1}	3910b	3805bc	4470a	4062A	3101cd	3389bc	4291a	3594A
Mean	3628A	3657A	3695A	3660	3212B	3274B	3509A	3332

++ As in Table 2. Means within columns and rows followed by the same lowercase letters; means within rows followed by the same uppercase letters; and means within columns followed by the same uppercase letters are not significantly different at P≤0.05.

Table 6. Effect of the combined use of FYM and inorganic fertilizers on sorghum grain yield (kg ha^{-1}) in 2002 and grain yield (kg ha^{-1}) pooled over five growing seasons.

	2002				Pooled grain yield			
FYM	0 F++	50 F	100 F	Mean	0 F++	50 F	100 F	Mean
0 t ha^{-1}	3785de	3813de	4131cde	3910B	3340g	3362fg	3726de	3476C
5 t ha^{-1}	3929de	4362bcd	4597bc	4296A	3549efg	3822cd	4075b	3816B
10 t ha^{-1}	3736de	5240a	4299b-e	4425A	3457fg	3997bc	4067b	3841B
15 t ha^{-1}	3683e	4856ab	5220a	4586A	3590def	4194b	4535a	4106A
Mean	3783B	4568A	4562A	4304	3484C	3844B	4101A	

++ As in Table 2. Means within columns and rows followed by the same lowercase letters; means within rows followed by the same uppercase letters; and means within columns followed by the same uppercase letters are not significantly different at P≤0.05.

Significant differences in fresh panicle yield were observed between the main effects of FYM and inorganic fertilizer treatments (Appendix Table 5.1). Fresh panicle yields increased from 4 377 kg ha^{-1} to 5 102 kg ha^{-1} with the application of 15 t FYM ha^{-1}. They were also increased from 4 366 kg ha^{-1} to 4962 kg ha^{-1} with the application of 100% of the recommended inorganic fertilizer rate.

Improvements in 1000-seed weight from the combined use of FYM and inorganic fertilizer were small, ranging between 3 to 6% (Appendix Table 5.1). The harvest index was in the range of 0.41 to 0.45 and was not affected by any of the treatment or interaction effects.

Yield Stability

The results of the regression analysis to assess the yield stability of treatments across a range of environments demonstrated variability between treatments (Table 7). A stable system has been defined as one that changes least in response to changes in environment (17). In this study, treatments marked with "+" are more stable as indicated by their smaller slope (b<1.0). This indicates that these treatments can produce reasonable consistent yield both in low yielding years and in good years, as they are less responsive to environmental changes. On the other hand treatments marked with "++" are less stable having steeper slopes (b>1.0). These treatments are responsive to environmental changes and may yield reasonably good in low yielding years and high in good years. These treatments are, thus, adapted to high-yielding environments. Generally, yield stability decreased with the applications of FYM and higher rates of inorganic fertilizer. However, although relatively less stable farmers would benefit from building up their soil fertility through the combined use of FYM and inorganic fertilizer as yield increases, even in bad years, are still better than the more stable treatments. Thus, building up the soil fertility would improve yield in any case although the benefit will be greater in good years.

Table 7. Stability analyses for the combined use of FYM and inorganic fertilizers.

Treatments	*a*	*b*	se	*p*-value	R^2	Categorical mark
0 t ha^{-1} FYM + 0F$^{\$}$	7030	0.69	0.21	0.046	0.78	+
0 t ha^{-1} FYM + 50F	1874	0.39	0.28	0.261	0.39	+
0 t ha^{-1} FYM + 100F	-1574	1.39	0.37	0.034	0.82	++
5 t ha^{-1} FYM + 0F	2104	0.38	0.22	0.193	0.48	+
5 t ha^{-1} FYM + 50F	-684	1.18	0.07	0.0004	0.98	++
5 t ha^{-1} FYM + 100F	-1799	1.54	0.41	0.033	0.82	++
10 t ha^{-1} FYM + 0F	2105	0.35	0.27	0.285	0.36	+
10 t ha^{-1} FYM + 50F	-2450	1.69	0.52	0.049	0.77	++
10 t ha^{-1} FYM + 100F	-1873	1.56	0.68	0.108	0.63	++
15 t ha^{-1} FYM + 0F	1044	0.67	0.40	0.193	0.48	+
15 t ha^{-1} FYM + 50F	-1038	1.37	0.31	0.021	0.86	++
15 t ha^{-1} FYM + 100F	1587	0.77	0.34	0.111	0.62	+

$^{\$}$Indicates % of the recommended inorganic fertilizer rates. + and ++ indicate stable and unstable treatments, respectively.

Nitrogen Concentration and Uptake

Stover and grain N concentrations were influenced by the main effects of FYM and inorganic fertilizer treatments, with the exception of stover N concentration with inorganic fertilizer treatments (Fig. 1). Averaged across inorganic fertilizer treatments, applications of 5, 10 and 15 t FYM ha^{-1} resulted in increased grain N concentrations over the FYM control, but differences between the FYM rates were not significant. Differences in grain N concentration between inorganic fertilizer treatments showed no consistent trend and were difficult to explain. Generally, grain N concentration values reported in this study, were within the range (1.23-2.44%) reported for sorghum by Muchow (11). Stover N concentrations tended to increase with increasing rates of FYM, although a significant difference was obtained only with the application of 15 t FYM ha^{-1}. The increase in stover N concentration with FYM applications indicates the availability of adequate levels of soil N and/or lower N translocation from the stover to the grain. With applications of FYM, translocation of N would not be great enough as there will be continued absorption until maturity. In agreement with this explanation Roy & Wright (27) indicated that the extent of translocation of N from the vegetative parts in fertilised plants would be low in comparison with that in unfertilised plants. According to Ruttunde et al. (28) the nitrogen content of the stover is an indicator of the stover feed quality. Thus, the increase in the nitrogen content of the stover with FYM applications, as in this study, would mean an improvement in the nutritive value of the stover, which would have major implications for resource poor farmers for whom sorghum stover is a major feed resource in the dry season.

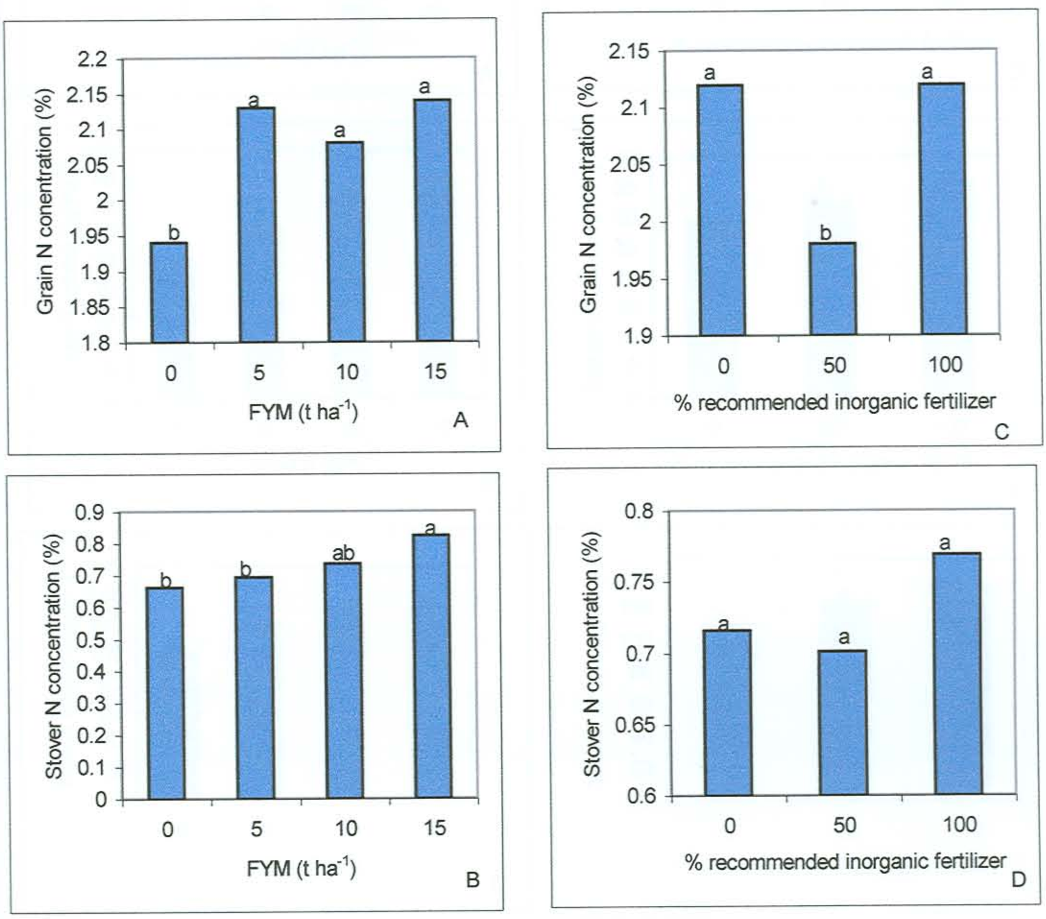

Figure 1. Effects of FYM and inorganic fertilizers on grain and stover N concentration. Values in A, and B are means across inorganic fertilizer rates; values in C and D are means across FYM rates. Bars with the same letter are not significantly different at P≤0.05.

N uptake in the grain, stover and whole plant (grain plus stover) was enhanced by increasing levels of FYM application (Fig. 2). Averaged over all inorganic fertilizer treatments, FYM applied at 5, 10 and 15 t ha^{-1} increased N uptake by 20, 20 and 29% in the grain, by 23, 43 and 57% in the stover and by 21, 26 and 36% in the whole plant compared to the FYM control.

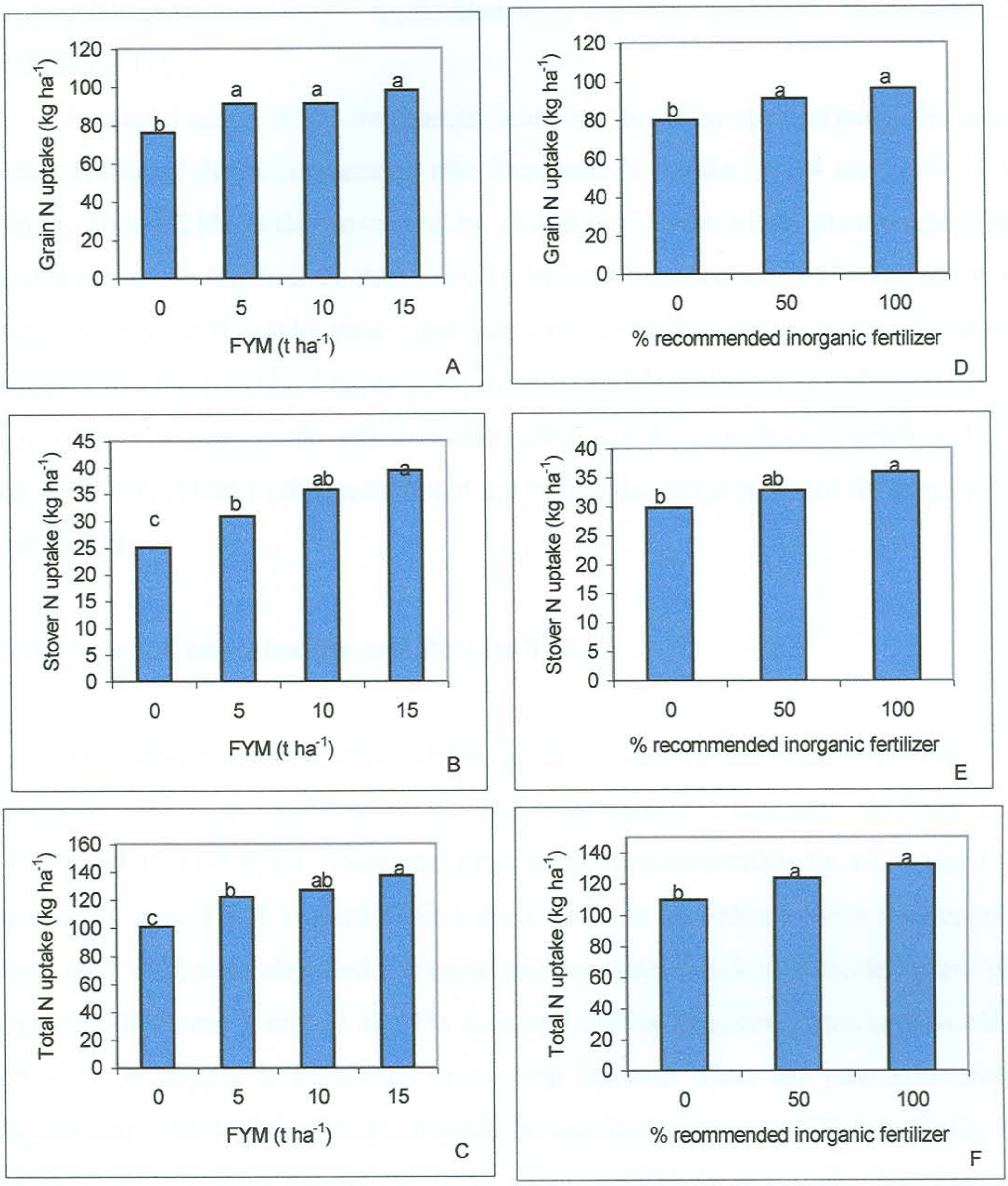

Figure 2. Effects of FYM and inorganic fertilizers on grain, stover and total plant N uptake. Values in A, B, and C are means across inorganic fertilizer rates; values in D, E, and F are means across FYM rates. Bars with the same letter are not significantly different at $P \leq 0.05$.

Increased N uptake with increased FYM applications could be ascribed to increased dry matter production and also to increased N concentration in plant tissue. N uptake increased with FYM application due to the build-up of organic N in the soil, from six successive annual applications, and its slow release throughout the growing period. As suggested by Yadav (24), it could also be due to the development of a higher root density, associated with the improved physical conditions of the soil, which in turn enhanced nutrient absorption capacity of the crop. Similar results of increased N uptake with FYM application were reported by Xie & Mackenzie (29) and Schlegel (30).

Averaged across FYM treatments, inorganic fertilizer application at the rate of 50 and 100% of the recommended rate increased N uptake by 14 and 20% in the grain, by 10 and 21% in the stover and by 13 and 21% in the whole plant, respectively over the inorganic fertilizer control (Fig. 2). Interaction effects of FYM and inorganic fertilizers on grain N uptake were significant, where the highest grain N uptakes were obtained from the combined application of 5, 10 and 15 t FYM with 50 and 100% of the recommended inorganic fertilizer rate (data not shown). Stover, grain and total plant N uptake values in this experiment are within the range reported for sorghum by Pal et al. (31).

Grain Protein Concentration and Protein Yield

The protein concentration of the grain was appreciably enhanced by FYM applications where, averaged across the inorganic fertilizer treatments, the application of 5, 10 and 15 t FYM ha^{-1} increased grain protein concentration by 10, 8 and 11%, respectively over FYM control (Table 8). This is in accordance with the report of Chang et al. (32) who observed increased protein concentrations in barley grain with manure applications. Grant et al. (33) indicated that protein concentrations would be high when N supply is high relative to crop demand. Thus the increased protein concentration with FYM application could be ascribed to improved N availability and greater N consumption during the grain filling period. In areas like NE Ethiopia, where cereal grains are a major source of proteins, any increase in grain protein content from improved fertility management would be a cost effective approach to the improvement of the nutrition of the people.

Similarly, FYM and inorganic fertilizer treatments affected grain protein yield. FYM, averaged over inorganic fertilizer treatments, increased grain protein yield by 20, 20 and 29% with the application of 5, 10 and 15 t ha^{-1}, respectively over the FYM control. Grain protein yield was also increased by 14 and 20% with the application of 50 and 100% of the recommended inorganic fertilizer rate (Table 8). Grain protein yield increased more when FYM and inorganic fertilizer were used in combination than when either was used alone. The combined application of 5, 10 and 15 t FYM

ha^{-1} with 50 and 100% of the recommended inorganic fertilizer rate increased grain protein yield by 22 to 46% over the control (data not shown). Metho et al. (34) also reported increased grain protein yield in wheat with the application of NPK fertilizers alone and in combination with manure. Nitrogen harvest index was not significantly affected by any of the treatments (Table 8), indicating that the observed difference in grain N content is due to the difference in N absorption rather than in partitioning the absorbed N into the grain.

Table 8. Effects of FYM and inorganic fertilizers on grain protein content, grain protein yield and N harvest index in 2002.

FYM (t ha^{-1})	GPC (%)	GPY (kg ha^{-1})	NHI
0	12.10b	475.4b	0.746a
5	13.30a (10)	571.2a (20)	0.748a
10	13.01a (8)	570.6a (20)	0.719a
15	13.39a (11)	612.4a (29)	0.707a
Fertilizer			
0F	13.24a	500.1b	0.729a
50F	12.36b	569.5a (14)	0.730a
100F	13.25a	602.6a (20)	0.730a
CV (%)	7.1	10.9	6.7

GPC, grain protein concentration; GPY, grain protein yield; NHI, nitrogen harvest index. 0F, 50F, and 100F represent 0, 50%, and 100% of the recommended inorganic fertilizer rate. Numbers in parenthesis indicate percent increases above the control. Means in a column accompanied by different letters are significantly different at $P \leq 0.05$ for each comparison.

Nitrogen Use Efficiency

FYM applications significantly improved the efficiency of applied inorganic N (Fig. 3). Nitrogen use efficiency with the combined application of 50% of the recommended inorganic fertilizer rate together with 5, 10 and 15 t FYM ha^{-1} was increased by 21, 73 and 57 kg kg^{-1} respectively, compared with 1.4 kg kg^{-1} when 50% of the recommended inorganic fertilizer rate was applied alone. Similarly, nitrogen use efficiency in the combined application of 100% of the recommended inorganic fertilizer rate together with 5, 10 and 15 t FYM ha^{-1} was increased to 16, 14 and 38 kg kg^{-1} respectively, compared with 8 kg kg^{-1} when 100% of the recommended inorganic fertilizer rate was applied alone. Significantly higher nitrogen use efficiency values were obtained with the application of 50% of the recommended inorganic fertilizer rate with 10 and 15 t FYM ha^{-1}. This observation agrees with the results of Yamoah et al. (15) who reported increased fertilizer use efficiency when crop residues and inorganic fertilizers were combined than when fertilizer was applied alone. The improved efficiency of inorganic fertilizer N, when used in conjunction with FYM, could be due to the fact that high root density, due to improved physical conditions of the soil and greater water availability, might have enhanced nutrient absorption capacity of the crop, thereby improving biological yield at a given level of fertilizer application (35). These results demonstrate that greater yields are attainable with a limited amount of inorganic fertilizer, if FYM is integrated in the nutrient supply system.

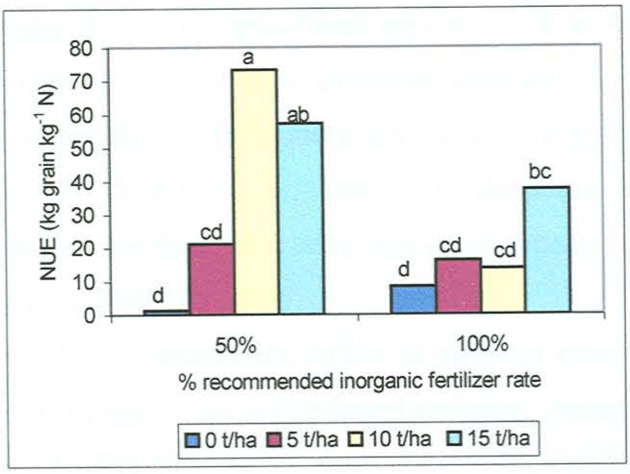

Figure 3. Effect of the combined use of FYM and inorganic fertilizer on nitrogen use efficiency (NUE). Bars with the same letter are not significantly different at $P \leq 0.05$.

CONCLUSION

An important finding of this study is that the combined use of FYM and inorganic fertilizer increased crop yield and quality at reduced inorganic fertilizer inputs, while maintaining and improving the soil resource. The results disprove farmers' concern that FYM can aggravate water stress under dry conditions and result in reduced yields. Results also demonstrated that 50% of the inorganic fertilizer recommended for sorghum production could be substituted by FYM without adverse effects on productivity, which implies a cost saving on inorganic fertilizers worth 20 kg N ha^{-1} and 10 kg P ha^{-1}. Application of 5, 10 and 15 t FYM ha^{-1} in combination with 100% of the recommended fertilizer rate and 5, 10 and 15 t FYM ha^{-1} in combination with 50% of the recommended fertilizer rate can be recommended for farmers who can and can not afford to buy inorganic fertilizers, respectively. However, the trial should be continued to assess the long-term effects of integrated use of FYM and inorganic fertilizers on soil physical and chemical properties, soil microbial activities, and interactions with other macro and micronutrient availability. Information on the economic feasibility and profitability of the integrated nutrient management systems in small-scale farming systems of NE Ethiopia also still needs to be addressed.

REFERENCES

1. Hailemichael, S. Crop breeding activities and achievements in northeastern Ethiopia, Welo. In *Agricultural research and technology transfer attempts and achievements in Northern Ethiopia;* Seboka, B., Deresa, A., Eds.; Ethiopian Agricultural Research Organization: Addis Ababa, Ethiopia, 1998; 3-10.
2. Bayu, W.; Getachew, A.; Mamo, T. Response of sorghum to nitrogen and phosphorus fertilization in semi-arid environments in Welo, Ethiopia. Acta Agron. Hungarica **2002**, *50*, 53-65.
3. Sharma, A.R.; Mittra, B.N. Effect of different rates of application of organic and nitrogen fertilizers in a rice-based cropping system. J. Agric. Sci. (Cambridge) **1991**, *117*, 313-318.
4. Palm, C.A.; Myers, R.J.K.; Nandwa, S.M. Combined use of organic and inorganic nutrient sources for soil fertility maintenance and replenishment. In *Replenishing soil fertility in Africa*; Buresh, R.J., Sanchez, P.A., Calhoun, F., Eds.: Soil Science Society of America: Madison, WI, 1997; Special publication No. 51, 193-217.
5. Kramer, A.W.; Doane, T.A.; Horwath, W.R.; Kessel, C.V. Combining fertilizer and organic inputs to synchronize N supply in alternative cropping systems in California. Agric. Ecosyst. Environ. **2002**, *91*, 233-243.
6. Sharma, A.R.; Mittra, B.N. Effect of combinations of organic materials and nitrogen fertilizer on growth, yield and nitrogen uptake of rice. J. Agric. Sci. (Camb.) **1988**, *111*, 495-501.
7. El-Shakweer, M.H.A.; El-Sayad, E.A.; Ewees, M.S.A. Soil and plant analysis as a guide for interpretation of the improvement efficiency of organic conditioners

added to different soils in Egypt. Commun. Soil Sci. Plant Anal. **1998**, *29*, 2067-2088.
8. Schjonning, P.; Christensen, B.T.; Carstensen, B. Physical and chemical properties of a sandy loam receiving animal manure, mineral fertilizer or no fertilizer for 90 years. Europ. J. Soil Sci. **1994**, *45*, 257-268.
9. Belay, A.; Claassens, A.S.; Wehner, F.C.; De Beer, J.M. Influence of residual manure on selected nutrient elements and microbial composition of soil under long-term crop rotation. S. Afr. J. Plant Soil **2001**, *18*,1-6.
10. Palm, C.A.; Gachengo, C.N.; Delve, R.J.; Cadisch, G.; Giller, K.E. Organic inputs for soil fertility management in tropical agro-ecosystems: Application of an organic resources database. Agric. Ecosys. Environ. **2001**, *83*, 27-42.
11. Muchow, R.C. Effect of nitrogen on partitioning and yield in grain sorghum under differing environmental conditions in the semi-arid tropics. Field Crops Res. **1990**, *25*, 265-278.
12. Page, A.L.; Miller, R.H.; Keeney, D.R. *Methods of soil analysis. Part 2. Chemical and microbiological properties*. 2nd Ed.; Soil Science Society of America: Madison, WI, 1982; 1159pp.
13. Kudasomannavar, B.T.; Kulkarni, G.N.; Patil, V.C. Effect of nitrogen and plant population on hybrid sorghum (CSH-1). I. Grain yield and its components. Mysore J. Agric. Sci. **1980**, *14*, 190-195.
14. Ogunlela, V.B.; Okoh, P.N. Response of three sorghum varieties to N supply and plant density in a tropical environment. Fert. Res. **1989**, *21*, 67-74.
15. Yamoah, C.F.; Bationo, A.; Shapiro, B.; Koala, S. Trend and stability analysis of millet yields treated with fertilizer and crop residues in the Sahel. Field Crops Res. **2002**, *75*, 53-62.
16. Gomez, K.A.; Gomez, A.A. *Statistical procedures for agricultural research*. John Wiley and Sons: New York, 1984; 680pp.
17. Raun, W.R.; Barreto, H.J.; Westerman, R.L. Use of stability analysis for long-term soil fertility experiments. Agron. J. **1993**, *85*, 159-167.
18. Subbarao, G.V.; Renard, C.; Payne, W.A.; Bationo, A. Long-term effect of tillage, phosphorus fertilization and crop rotation on pearl millet-cowpea productivity in the West-African Sahel. Expl. Agric. **2000**, *36*, 243-264.

19. Lungu, O.I.; Temba, J.; Chirma, B.; Lungu, C. Effects of lime and farmyard manure on soil acidity and maize growth on an acid Alfisol from Zambia. Trop. Agric. (Trinidad) **1993**, *70*, 309-314.

20. Prasad, P.V.V.; Satyanarayana, V.; Murphy, V.R.K.; Boote, K.J. Maximizing yields in rice-groundnut cropping sequence through integrated nutrient management. Field Crops Res. **2002**, *75*, 9-21.

21. Satyanarayana, V.; Prasad, P.V.V.; Murthy, V.R.K.; Boote, K.J. Influence of integrated use of farmyard manure and inorganic fertilizers on yield and yield components of irrigated lowland rice. J. Plant Nutr. **2002**, *25*, 2081-2090.

22. Hegde, D.M. Long-term sustainability of productivity in an irrigated sorghum-wheat system through integrated nutrient supply. Field Crops Res. **1996**, *48*,167-175.

23. Yadav, R.L.; Dwivedi, B.S.; Prasad, K.; Tomar, O.K.; Shurpali, N.J.; Pandey, P.S. Yield trends, and changes in soil organic-C and available NPK in a long-term rice-wheat system under integrated use of manures and fertilizers. Field Crops Res. **2000**, *68*, 219-246.

24. Yadav, R.L. On-farm experiments on integrated nutrient management in rice-wheat cropping systems. Expl. Agric. **2001**, *37*, 99-113.

25. Reddy, D.D.; Rao, A.S.; Reddy, K.; Takkar, P.N. Yield sustainability and phosphorus utilization in soybean-wheat system on vertisols in response to integrated use of manure and fertilizer phosphorus. Field Crops Res. **1999**, *62*, 181-190.

26. Ma, B.L.; Dwyer, L.M.; Gregorich, G.E. Soil nitrogen amendment effects on nitrogen uptake and grain yield of maize. Agron. J. **1999**, *91*, 650-656.

27. Roy, R.N.; Wright, B.C. Sorghum growth and nutrient uptake in relation to soil fertility. II. N, P, and K uptake pattern by various plant parts. Agron. J. **1974**, *66*, 5-10.

28. Ruttunde, H.F.W.; Zerbini, E.; Chandra, S.; Flower, D.J. Stover quality of dual-purpose sorghums: Genetic and environmental sources of variation. Field Crops Res. **2001**, *71*, 1-8.

29. Xie, R.; Mackenzie, A.F. Urea and manure effects on soil nitrogen and corn dry matter yields. Soil Sci. Soc. Am. J. **1986**, *50*, 1504-1508.

30. Schlegel, A.J. Effect of composted manure on soil chemical properties and nitrogen use by grain sorghum. J. Prod. Agric. **1992**, *5*, 153-157.

31. Pal, U.R.; Singh, V.P.; Singh, R.; Verma, S.S. Growth rate, yield and nitrogen uptake response of grain sorghum (*Sorghum bicolor* (L) Moench) to nitrogen rates in humid subtropics. Fert. Res. **1983**, *4*, 3-12.

32. Chang, C.; Sommerfeldt, T.G.; Entz, T. Barley performance under heavy applications of cattle feedlot manure. Agron. J. **1993**, *85*, 1013-1018.

33. Grant, C.A.; Gauer, L.E.; Gehl, D.T.; Bailey, L.D. Protein production and nitrogen utilization by barley cultivars in response to nitrogen fertilizer under varying moisture conditions. Can. J. Plant Sci. **1991**, *71*, 997-1009.

34. Metho, L.A.; Taylor, J.R.N.; Hammes, P.S.; Randall, P.G. Effects of cultivar and soil fertility on grain protein yield, grain protein content, flour yield and bread making quality of wheat. J. Sci. Food Agric. **1999**, *79*, 1823-1831.

35. Boparai, B.S.; Singh, Y.; Sharma, B.D. Effect of green manuring with *Sesbania aculeate* on physical properties of soil and growth of wheat in rice-wheat and maize-wheat cropping sequence in semi-arid regions of India. Arid Soil Res. Rehab. **1992**, *6*, 135-143.